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(54) Title: RESOLUTION ENHANCEMENT SYSTEM FOR BINARY IMAGES		
(57) Abstract <p>An image processing system for providing edge enhancement of low resolution binary image files processes the low resolution bitmap data in windows to determine whether an edge transition or "kink site" occurs within each window. The original bitmap data in the window is then replaced with edge enhanced gray scale data if a kink site is identified. The selection of the correct edge enhanced gray scale data to be used in place of the original bitmap data is based on whether the central pixel contained within the window is a black or white pixel, whether the central pixel is located on a single pixel line, and the location of the central pixel with respect to the kink site. The determination of the location of the central pixel is based on pixel values and gradient magnitudes of surrounding pixel locations. The system for performing edge enhancement of low resolution image files may employ a binarization and sorting unit (110) to sort data that is indicative of binary data from a mixed low resolution image input file. The sorted binary data is then supplied to a binary data edge enhancement processor (120) for edge enhancement processing. The output from the binary data edge enhancement processor unit is supplied to a data merger unit (130) along with the original image data. The data merger unit determines whether the original image data was part of a gray-scale image. If the data is part of a gray-scale image, the original data is supplied as the output of the processing system. Otherwise the output from the binary edge enhancement processing unit is supplied as the output of the processing system.</p> <div data-bbox="673 1165 1404 1764"><pre>graph LR; A[MIXED LOW RESOLUTION IMAGE DATA] --> B[INPUT BUFFER 100]; B --> C[BINARIZATION AND SORTING UNIT 110]; C --> D[BINARY EDGE ENHANCEMENT PROCESSOR UNIT 120]; B --> E[OUTPUT DATA MERGE UNIT 130]; D --> E;</pre></div>		

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RESOLUTION ENHANCEMENT SYSTEM FOR BINARY IMAGESField of the Invention

The invention relates generally to digital
5 image processing and, more specifically, to a digital
image processing system for enhancing the edge
characteristics of printed or displayed images that are
generated from low resolution image files that include
binary image data alone or a mixture of binary and
10 gray-scale data.

Background

Edge or line jaggedness is a common problem
associated with the printing of low resolution binary
15 image data. Efforts have been made to reduce or
overcome line jaggedness using template matching
methods that are applied to low resolution bitmaps as
described in U.S. Patent 5,005,139 or, alternatively,
through the use of an outline extraction method like
20 that described in the article entitled "Image Makers",
by Henry Bortman, MacUser, November 1991, pages 98-103.
Both of the above-referenced methods use a low
resolution bitmap as an input file and both methods
perform digital processing operations on the low
25 resolution bitmap to produce an enhanced image output
file. The enhanced output file is supplied to the
printhead or a printer to produce a hard copy of the
image.

There are disadvantages, however, to both of
30 the template matching and outline extraction methods of
edge enhancement discussed above. In the template
matching method, the number of templates that can be
employed must be limited in order to maintain
acceptable processing speeds. If a pattern within the
35 bitmap data contained in the input file does not happen
to match one of the available templates, an edge
resolution enhancement operation cannot be performed

regardless of the quality of the image that will be produced from the input data. In the outline extraction method, variable dot sizes are used to "fill in" and match a character's outline. The fill in process, however, can be difficult when small fonts are employed. In addition, the outline extraction method tends to broaden thin graph lines that are spaced close together which results in the merger of multiple lines and a perceivable reduction in the resolution of the printed image.

Another drawback to the above-described processes is that they tend to have a negative impact on the gray scale halftone data. Thus, the processes are not particularly well suited for processing mixed image data files containing both binary image data and gray-scale halftone image data. Mixed data files, however, are becoming more and more common. Many imaging systems, for example, now combine text data with gray-scale halftoned image data and binary graphic data in a single image.

It is an object of the invention to provide a method and apparatus for providing edge enhancement using a low resolution bitmap as an input file without suffering the resolution degradation associated with the outline extraction method and the drawbacks of the template matching outlined above.

It is also an object of the invention to provide a system for providing edge enhancement of mixed image files containing both binary image data and gray-scale image data without adversely affecting the gray-scale image data.

SUMMARY OF THE INVENTION

In accordance with one aspect of the invention, there is provided an image processing system comprising: means for storing a binary bitmap image file including a plurality of pixel locations; means for determining a gradient magnitude corresponding to

each pixel location of the binary bitmap image file;
means for determining a gradient direction
corresponding to each pixel location of the binary
bitmap image file; decision matrix means for comparing
5 a window of the binary bitmap image file and the
gradient magnitudes and directions corresponding
thereto to predetermined sets of criteria and means
responsive to said decision matrix means for generating
enhanced gray-scale image data.

10 In accordance with another aspect of the
invention, there is provided a method of providing edge
enhancement of binary image data comprising the steps
of storing a binary bitmap image file including a
plurality of pixel locations; determining a gradient
15 magnitude corresponding to each pixel location of the
binary bitmap image file; determining a gradient
direction corresponding to each pixel location of the
binary bitmap image file; comparing a window of the
binary bitmap image file and the gradient magnitudes
20 and directions corresponding thereto to predetermined
sets of criteria and in response to the comparing,
generating enhanced gray-scale image data.

In accordance with a third aspect of the
invention, there is provided an image processing system
25 comprising: means for storing mixed image data
including binary image data and gray-scale image data;
means for sorting the mixed image data to generate
sorted binary image data; means for performing edge
enhancement of the sorted binary image data to produce
30 gray-scale enhanced binary image data; means for
selecting the mixed image data as the output of the
image processing system if the mixed image data
includes gray-scale image data and for selecting the
gray-scale enhanced binary image data if the mixed
35 image data is binary image data.

In accordance with a fourth aspect of the
invention, there is provided an image processing method

comprising the steps of storing mixed image data including binary image data and gray-scale image data, sorting the mixed image data to generate sorted binary image data; performing an edge enhancement operation on
5 the sorted binary image data to produce gray-scale enhanced binary image data; selecting the mixed image data as a system output if the mixed image data includes gray-scale image data; and selecting the gray-scale enhanced binary image data as a system output if
10 the mixed image data is binary image data.

BRIEF DESCRIPTION OF THE DRAWINGS

With the above as background, reference should now be made to the following description of the
15 best mode for carrying out the invention and the accompanying drawings wherein:

FIG. 1 is a functional block diagram of an edge enhancement processing system in accordance with a preferred embodiment of the invention and in accordance
20 with the embodiment of FIG. 51;

FIG. 2 is an example of binary bitmap data applied to the input of the edge enhancement processing system shown in FIG. 1;

FIG. 3 is a gradient magnitude map of the
25 binary bitmap data shown in FIG. 2;

FIG. 4 is a gradient angle map of the binary bitmap data shown in FIG. 2;

FIG. 5 is a functional flow diagram of the operation of the decision matrix employed in the edge
30 enhancement processing system shown in FIG. 1;

FIG. 6 illustrates an 8 x 8 window of binary data for a near-vertical line;

FIG. 7 illustrates the gradient directions corresponding to each pixel location of the window
35 shown in FIG. 6;

FIG. 8 illustrates the gradient magnitudes corresponding to each pixel location of the window shown in FIG. 6;

FIG. 9 illustrates a 3 x 5 window of binary data for a near horizontal line;

FIG. 10 illustrates the gradient directions corresponding to each pixel location of the window shown in FIG. 9;

FIG. 11 illustrates the gradient magnitudes corresponding to each pixel location of the window shown in FIG. 9;

FIGS. 12-14 respectively illustrate pixel values, gradient directions and gradient magnitudes for a 5 x 3 window of pixels surrounding a kink site located in the 8 x 8 window of FIG. 6;

FIGS. 15-17 respectively illustrate the pixel values, gradient directions and gradient magnitudes shown in FIGS. 12-14 rotated to a preferred orientation;

FIGS. 18-20 respectively illustrate the pixel values, gradient directions and gradient magnitudes shown in FIGS. 9-11 rotated to a preferred orientation;

FIG. 21 illustrates a template that is utilized to identify a kink site;

FIGS. 22-24 respectively illustrate the pixel value, gradient direction and gradient magnitude maps for a central pixel having a gradient direction of one;

FIGS. 25-27 respectively illustrate the pixel value, gradient direction and gradient magnitude maps for a central pixel having a gradient direction of two;

FIGS. 28-30 respectively illustrate the pixel value, gradient direction and gradient magnitude maps for a central pixel having a gradient direction of three;

FIGS. 31-33 respectively illustrate the pixel value, gradient direction and gradient magnitude maps

for a central pixel having a gradient direction of four;

FIGS. 34-36 respectively illustrate the pixel value, gradient direction and gradient magnitude maps for a central pixel having a gradient direction of five;

FIGS. 37-39 respectively illustrate the pixel value, gradient direction and gradient magnitude maps for a central pixel having a gradient direction of six;

FIGS. 40-42 respectively illustrate the pixel value, gradient direction and gradient magnitude maps for a central pixel having a gradient direction of seven;

FIGS. 43-45 respectively illustrate the pixel value, gradient direction and gradient magnitude maps for a central pixel having a gradient direction of eight;

FIG. 46 is a window illustrating a one pixel wide horizontal line;

FIG. 47 illustrates the gradient directions corresponding to the pixel locations shown in FIG 46;

FIG. 48 is a window illustrating a one pixel wide vertical line;

FIG. 49 illustrates the gradient directions corresponding to the pixel locations shown in FIG. 48;

FIG. 50 is an example of enhanced gray-scale output data corresponding to the original binary image data illustrated in FIG. 12;

FIG. 51 is a functional block diagram of an edge enhancement processing system in accordance with the present invention;

FIG. 52 is a 3 x 3 window of original image data containing gray-scale data that is supplied to the binarization and sorting unit shown in Fig. 51;

FIG. 53 is a 3 x 3 window of sorted image data produced from the binarization and sorting unit

shown in Fig. 51 when the mixed image data of Fig. 52 is applied thereto;

FIG. 54 is a 3 x 3 window of original image data containing binary data that is supplied to the binarization and sorting unit shown in Fig. 51; and

FIG. 55 is an 8 x 8 window illustrating a special case of a single pixel line in which the first pixel of a kink site overlaps an adjacent pixel.

10

BEST MODE OF CARRYING OUT THE INVENTION

The preferred embodiment to be described provides a system and method for performing edge enhancement of low resolution binary image files that is flexible and adaptable to high speed processing operations without causing a degradation in image resolution. Operations are performed by the system to obtain outline gradient magnitudes and directions which are used, in combination with the original bitmap data, to reduce the tangential gradient magnitude change (jaggedness) of lines or text within a printed image while preserving the gradient angle (shape of the line or text) without sacrificing the normal gradient magnitude (sharpness of the line or text).

Specifically, the system processes the low resolution bitmap data in sections or windows to determine whether an edge transition or "kink site" occurs within each window. The original bitmap data in the window is then replaced with edge enhanced gray scale data if a kink site is identified. The selection of the correct edge enhanced gray-scale data to be used in place of the original bitmap data is based on whether the central pixel contained within the window is a black or white pixel, whether the central pixel is located on a single pixel line and the location of the central pixel with respect to the kink site. The determination of whether the central pixel is a black or white pixel is based on the binary value assigned to

the pixel, the determination of the location of the central pixel with respect to the kink site is based on pixel values and gradient magnitudes of surrounding pixel locations, and the determination of whether the
5 central pixel is located on a single pixel line is based on the gradient magnitude of the central pixel and surrounding pixel locations.

Preferably, the system determines the gradient angles of the pixels contained within the
10 window prior to performing the operations described above. A limited number of gradient directions are then assigned to the pixels based on the gradient angles. The system uses the gradient directions to rotate the window to a selected reference direction in order to
15 simplify the identification of kink sites within the window and the selection of the edge enhanced gray scale data as will be described in greater detail below.

A further embodiment provides a system for
20 performing edge enhancement of mixed low resolution image files that is flexible and adaptable to high speed processing operations without causing a degradation in image resolution. The system employs a binarization and sorting unit to sort data that is
25 indicative of binary data from the mixed low resolution image input file. The sorted binary data is then supplied to a binary data edge enhancement processor for edge enhancement processing. The output from the binary data edge enhancement processor unit is supplied
30 to a data merger unit along with the original image data. The data merger unit determines whether the original image data included gray-scale image data. If the data merger determines the original data does include gray-scale image data, the original data is
35 supplied as the output of the processing system. If the data merger determines that the original data is binary image data, the output from the binary edge enhancement

processor unit is supplied as the output of the processing system.

A functional block diagram of an edge enhancement processing system in accordance with the invention is illustrated in Fig. 1. A low resolution binary bitmap (300 dpi or 11.86 dots per mm) generated for example by using a commercially available software package such as PostScript, is stored in a band buffer 10, where $n(i,j)$ is a pixel value within the bitmap at location (i,j) . The term "binary" bitmap or image will be understood by those skilled in the art to refer to a bit map or image in which image pixels are either fully exposed or are unexposed, i.e. no gray-scale pixel data is present. The term "gray-scale" refers to image data wherein each pixel is represented by more than one bit of data to indicate one or more shades of gray between fully exposed and unexposed. Of course, the color of the pixel will be dependent upon the color toner or pigment used to develop same. An example of such a binary bitmap for a portion of the letter "R" is illustrated in FIG. 2 in which exposed areas of an image (in the illustrated embodiment) are identified in this example by the numeral 255 (i.e. pixel exposed) and non-exposed areas are identified by zero (i.e. pixel not exposed).

Sobel gradient masks 12, 14 for both the horizontal (sobelx) and vertical (sobely) directions operate on the binary bitmap data $n(i,j)$ to produce a gradient x operator (gx) and a gradient y operator (gy). Typical sobel gradient masks that can be employed include:

sobelx = (-1 0 1, -2 0 2, -1 0 1)
where $gx(i,j) = sobelx * n(i,j)$; and
sobely = (-1 -2 -1, 0 0 0, 1 2 1)
where $gy(i,j) = sobely * n(i,j)$

The gradient magnitude (gm) 16 is then calculated by taking the square root of the sum of the square of the gradient x operator (gx) and the square of the gradient y operator (gy) for each location in the bitmap to produce a gradient magnitude map, as shown in Fig. 3. The gradient magnitude map is then stored in the a buffer 18 for later use. I

$$gm(i,j) = \text{sqrt}(gx(i,j)^2 + gy(i,j)^2)$$

Similarly, the gradient angle (ga) 20 is determined for each location using the equation:

$$ga(i,j) = \text{tan-1}(gy(i,j)/gx(i,j))$$

to produce a gradient angle map as shown in Fig. 4. It should be noted that an arctangent calculation can also be employed to calculate ga if desired.

For purposes of convenience, the gradient angle ga is preferably limited to a choice of gradient directions gd by a gradient direction sorter 24. For example, eight directions are preferably employed using the following sort criteria:

gd = 2, if (68° >= ga > 23°)
gd = 3, if (113° >= ga > 68°)
gd = 4, if (158° >= ga > 113°)
gd = 5, if (203° >= ga > 158°)
gd = 6, if (248° >= ga > 203°)
gd = 7, if (293° >= ga > 248°)
gd = 8, if (338° >= ga > 293°)

gd = 1, if ga is between 338 and 23 degrees and gm isn't zero

$$gd = 0, \text{ if } gm = 0$$

The gradient direction for each location is also stored in a buffer 26. It should be noted that the use of a finer separation criteria (i.e. more than eight directions) for gd can be employed if desired.

The original bitmap data and the gradient magnitudes gm and gradient directions gd corresponding thereto are supplied to a decision matrix 28, which uses this information to select edge enhanced gray-scale output data to replace the original binary bitmap data. In a preferred mode of operation, the decision matrix 28 determines whether the central pixel of a window of the original bitmap data is black or white pixel, whether the central pixel is contained in a single pixel line and the position of the pixel with respect to a kink site, by comparing the pixel data to a set of criteria represented by predetermined pixel values and gradient magnitudes. In accordance with rules establishing a set of criteria, the decision matrix generates an address that is supplied to a LUT 30. The LUT 30 generates edge enhanced gray-scale output data based on the address generated by the decision matrix 28. The enhanced gray scale output data replaces the original binary input data and produces a smoother image without jagged edges when applied to a gray scale printhead (for example a laser, LED thermal, inkjet or other type of printhead) of a printer or to a gray level display such as a CRT or other suitable display.

It should be noted that the illustrated system can be implemented as a computer program executed on a general purpose computer in hardware as a pipelined processing system, preferably in the form of an application specific integrated circuit (ASIC), or a combination thereof. Processing speeds can be improved by precalculating the gradient magnitudes and directions for all possible combinations of binary data within the window and storing the precalculated values within gradient magnitude and gradient direction LUTs. In operation, a window of binary data is supplied as an address to the gradient magnitude and gradient direction LUTs which then generate corresponding

gradient magnitude and directions maps. The operation of the decision matrix can similarly be implemented with LUTs by supplying the original binary input data and corresponding gradient magnitude and direction information as an address thereto.

A general flow diagram of the operation of a decision matrix as implemented in software is illustrated by the decision tree in Fig. 5. Fig. 6 illustrates an 8 x 8 window of data retrieved from the original binary bitmap data previously stored in the band buffer. While an 8 x 8 window is shown, it is preferred to have larger windows such as 9 x 9 or greater. The pixel values illustrated in Fig. 6 are for a section of a near vertical line that is greater than one pixel in width. Figs. 7 and 8, respectively, illustrate the gradient directions and magnitudes corresponding to each of the pixel values illustrated in Fig. 6. In this example, exposed pixels are denoted by the numeral fifteen and non-exposed pixels are denoted by zero.

The decision matrix first orients the pixel data via a rotation operation in order to decrease the number of template comparisons with the rules or sets of criteria that will be required to identify kink sites requiring edge correction. For example, a near vertical edge (see the circled second black pixel of a kink site shown in Fig. 6) can either be approached from the left (gd = 1) or the right (gd = 5) while a near horizontal line can be approached either from the top (gd = 3) or the bottom (gd = 7). An example of a near horizontal line segment is shown in Figs. 9-11. In the case of the vertical line approached from the right, a 5 x 3 window of pixels surrounding the second black pixel of the kink site of the near vertical line as shown in Figs. 12-14 can be rotated to a position illustrated in Figs. 15-17 based on the direction of the second black pixel. Similarly, a 3 x 5 window of

pixels surrounding the second black pixel (circled) of the kink site of the near horizontal line as shown in Figs. 9-11 can also be rotated to a position illustrated in Figs. 18-20. As the pixel values are identical for the rotated segments as shown in Figs. 15 and 18, a single template or substitute bit map pattern can be used to identify kink sites in both near vertical lines approached from the right and the near horizontal lines approached from the top and the same enhanced gray-scale data can therefore be employed to smooth the kink site in both cases. In fact, all of the near vertical and near horizontal lines (for all four possible directions of approach) can be sorted through the rotation operation into a template matching the pixel configuration of Figs. 15 and 18 or a template matching the configuration shown in Fig. 21, rather than the eight bit maps that would be required to be analyzed (two for each direction) if rotation were not employed. A similar procedure is utilized for near diagonal line segments (i.e. $gd = 2, 4, 6$ or 8).

The rotation of the pixels within the windows is accomplished by a simple remapping routine. Figs. 22-45 illustrate how the pixel values, gradient magnitudes and gradient direction correspond for each direction. For purposes of illustration, the pixel values for each pixel within the 9×9 window are denoted as $V(x\ y)$, where V is the pixel value, x is a row position within the 9×9 window and y is a pixel position within the row. For example, as shown in Fig. 22, the pixel value of the central pixel within the 9×9 window is denoted by $V15$. Similarly, the gradient direction and magnitude for each pixel within the window is respectively denoted by $d(x\ y)$ and $a(x\ y)$.

In addition to rotating the pixel window to a predetermined direction, the pixel value of the central pixel within the window is analyzed to determine whether the pixel is a black pixel or a white pixel,

whether the central pixel is located within a single pixel line and the location of the central pixel with respect to the kink site, as each of these factors can influence the type of enhanced data utilized to smooth the kink site. The determination of whether the pixel is black or white is made by a simple comparison of the pixel value to the value assigned to an exposed pixel. For example, in the embodiment just discussed, the central pixel is a black pixel if the pixel value is fifteen ($V_{15} = 15$) and the central pixel is a white pixel if the pixel value is zero ($V_{15} = 0$). The determination of whether the central pixel is located within a single pixel line is made by comparing the gradient direction of the central pixel to the gradient directions of surrounding pixels. For example, for the lower of the two horizontal single lines illustrated in Fig. 46, the second black pixel (circled) from the kink site has a direction of zero, while the pixel location above the second black pixel has a direction of three and the pixel location below the second black pixel has a direction of seven (see Fig. 47). Similarly, the second black pixel (circled) from a kink site of a vertical single pixel line (left most of the two lines) shown in Fig. 48 has a direction of zero, while the pixel location to the left has a direction of one and the pixel location to the right has a direction of five (see Fig. 49). The determination of the location of the pixel with respect to the kink site is based on the gradient magnitude of the pixel location and adjacent pixel locations. For example, the gradient magnitude will always be the highest value for the first pixel location of a kink site at a non-single pixel line. Thus, the pixel values and gradient amplitudes can be compared with a template to determine whether the central pixel is the first, second, third or fourth pixel from the kink site. If desired, a backfill template can also be employed if a white pixel is not

identified as the first through fourth pixel from a kink site. That is, one or more gray-scale pixels will be added to a location(s) that features a white pixel where the gradient magnitude of the pixels in the
 5 gradient direction of the current pixel is changing.

As shown in Fig. 5, it is preferable to make the decision of whether the pixel is a white or black pixel and then proceed immediately with a determination of whether the pixel is the first pixel of a kink site,
 10 before making a determination of whether the pixel is the first pixel of a single line. If the pixel does not fall into one of these two latter categories, a general decision is made as to whether the pixel is in a single line. The determination of whether the pixel
 15 is the first pixel of a single line is made using a different criteria than the criteria used for the general decision in the subsequent step in order to cover a special case where the first pixel of the kink site in a single line overlaps an adjacent pixel as
 20 shown in Fig. 55. If a criteria were used in which a change in direction were required from both sides of the pixel in order to identify a single pixel line, the case of the overlapped first pixel would not be caught.

The following are examples of comparisons
 25 that are preferably applied to the pixel values and gradient magnitudes to determine whether the central pixel is:

a) the first black pixel of a kink site (not
 30 a single pixel line) if: $a_{15} > a_{14}$, & $a_{15} > a_{16}$, & $V_{35} \neq 0$ & $V_{25} = 0$, & $V_{26} = 0$, & $V_{45} = 0$, & $V_{36} \neq 0$, & $V_{55} \neq 0$, & $((V_{24} \neq 0, V_{16} = 0, \& V_{14} \neq 0) \text{ or } (V_{27} \neq 0, \& V_{14} = 0, \& V_{16} \neq 0))$;

b) the first black pixel of a kink site in a
 35 single pixel line if: $(V_{15} \neq 0, \& (V_{14} \neq 0, \& V_{13} \neq 0, \& V_{16} = 0, \& V_{17} = 0, \& ((V_{26} \neq 0, \& V_{27} \neq 0, \& V_{24} = 0, \&$

V23 = 0) or (V36 \neq 0 & V37 \neq 0 & V34 = 0, & V33 = 0)))
 or (V16 \neq 0, & ~~V17 \neq 0~~, & V13 = 0, V14 = 0, & ((V23 \neq 0
 & V24 \neq 0, & V26 = 0, & V27 = 0) or (V33 \neq 0, & V34 \neq 0,
 & V36 = 0, & V37 = 0))))); and

5

c) the first white pixel of a kink site in a
 single pixel line if: (V15 = 0, & V35 \neq 0, & ((V13 = 0;
 & V14 = 0, & V16 \neq 0, & V17 \neq 0, & V34 \neq 0) or (V13 \neq 0,
 & V14 \neq 0, & V16 = 0, & V17 = 0, & V36 \neq 0)) & ((a15 >
 10 a14, & a15 \leq a16) or (a15 \leq a14, & a15 > a16))).

Similar criteria are used for each of the
 other decisions illustrated in Fig. 5. Once a match is
 established, an address is generated and supplied to
 15 the LUT in order to generate corresponding enhanced
 gray-scale data which is subsequently supplied to the
 gray-scale printhead of a printer or to a display.
 See, for example, the enhanced gray-scale data shown in
 Fig. 50 which corresponds to the original data shown in
 20 Fig. 12. The actual values of the enhanced gray-scale
 data to be utilized in place of the binary input data
 depends on the characteristics of the printer or
 display to which the enhanced data is to be supplied
 and a subjective determination of what is considered
 25 acceptable to the end viewers of the printed images.
 The original binary bitmap data is used if no match
 occurs.

Some basic rules, however, do apply in
 generating the enhanced data to be stored in the LUT.
 30 For example, looking at some kink sites in the
 downstroke of the letter R in the gradient magnitude
 map of Fig. 3 and the gradient angle map of Fig. 4, it
 is noted that the gradient magnitude is at a peak value
 right at the kink site with respect to the gradient
 35 magnitude of the pixels along the gradient direction
 (the gradient direction being along the tangential
 direction of the line). Thus, for an exposed pixel, it

is desirable to reduce the exposure at that kink site to reduce jaggedness. In contrast, it is desirable to increase the exposure of the white pixel at the kink site, which also has the gradient magnitude at its peak, to reduce line jaggedness, provided that one of the pixel values along the gradient direction is not zero which signifies that the white kink site is indeed a kink site. Similar sets of rules can be written to take care of black or white pixels at a certain distance to the kink site to have a gradual line width change to reduce tangential gradient magnitude changes. It should be noted that the exposure value of the exposed and non-exposed pixels is not changed on the upper portion of the letter R, since no kink site is defined (gradient change along the gradient direction of the search turns out a similar gradient magnitude). Therefore, the normal gradient magnitude or sharpness of the letter is not reduced. Other rules can be written to take care of single pixels.

The system preferably makes use of a variable window depending on the gradient angle (or direction) change of the pixels along the gradient angle. For example, the problem of line jaggedness usually occurs at near horizontal or near vertical lines. For the case of a near horizontal line, a larger window (preferably rectangular with a long axis in the direction of the line segment) along the direction of the gradient direction can be utilized. If the gradient direction of the pixels is not changing much, a longer window is used. For 400 dpi (15.81 dots per mm), a window of about 20 pixels length in one direction is about right or 10 pixels from the original position on both sides. Then if a kink site is hit, usually signifying a large change in gradient magnitude and direction --like from an angle of 180 to 153 degree change in a near vertical case --, the current pixel location with respect to the

kink site will give the LUT necessary information for the modification.

A functional block diagram of an edge enhancement processing system for processing mixed data in accordance with another embodiment of the invention is illustrated in Fig. 51. A mixed low resolution image file, in the form of a bitmap having a plurality of pixel locations containing either gray-scale image data or binary image data, is supplied to input buffer 100. The bitmap is subsequently supplied to a binarization and sorting unit 110, which passes only sorted data that is indicative of binary image data to a binary edge enhancement processor unit 120. The binary edge enhancement processor unit 120 performs edge enhancement processing operations on the sorted data to produce edge enhanced sorted data that is supplied to an output data merge unit 130. The output merge unit 130 analyzes the original bitmap data supplied to the binarization and sorting unit 110 to determine whether the original bitmap data was gray-scale image data or binary image data. If the original data was gray-scale image data, the output data merger unit 130 supplies the original data from the input buffer 100 as the output of the system. If the original data, however, was binary image data, the output data merger unit 130 supplies the edge enhanced sorted data received from the binary edge enhancement processor unit 120 as the output of the system.

An example of the operation of the system will be discussed with references to Figs. 52-54. Fig. 52 illustrates a 3 x 3 window of gray-scale image data supplied to the binarization and sorting unit 110. The binarization and sorting unit 110 passes only those pixel values that are indicative of binary image information, namely, a value of fifteen for an exposed pixel or a value of zero for a non-exposed pixel for the illustrated example (assuming a four bit 0-15 gray-

scale), to the binary edge enhancement processor unit 120. Those pixel locations containing a gray-scale data are filled with zeros as illustrated in Fig. 53. The binary edge enhancement processor unit 120 then

5 performs an edge enhancement processing operation on the data shown in Fig. 53. The output data merge unit 130 analyzes the original data illustrated in Fig. 52 to determine whether gray-scale information is present. A simple comparison operation, for example, can be used

10 to compare each pixel value within the window to either zero or fifteen. If the pixel value does not fall within this criteria, as is the case for the data illustrated in Fig. 52, the output data merge unit 130 passes the original data to the output of the system,

15 thereby avoiding any possible distortion of the gray-scale data. In the case where the original bitmap data is binary image data, for example as shown in Fig. 54, the sorted data supplied by the binarization and sorting unit 110 to the binary edge enhancement

20 processor unit 120 will be identical to the original data. The output data merge unit 130 will then select the edge enhanced data produced by the binary edge enhancement processor unit 120 as the output of the system.

25 It will be understood that the binary edge enhancement processor unit 120 can be implemented with any of the previously discussed conventional binary image edge enhancement systems. A preferred edge enhancement processor to be used in the binary edge

30 enhancement processor unit 120, however, is that shown and described above in detail.

An advantage of the edge enhancement system is that it is not necessary to provide a set of criteria for comparison with every possible bit map

35 pattern. Rather, the bit map patterns can be rotated to form a template that can be compared to a set of criteria for analyzing the template. There is thereby

provided a reduction in the set of criteria and no need to store a multitude of templates for which an exact match is required as is done in conventional template matching methods. In addition, the edge enhancement system reduces line jaggedness with little sharpness degradation, in contrast to conventional outline extraction methods in which the outline of the text is traced by linking the maximum gradient magnitude points together. The outline extraction method runs into problems when the fonts in the image to be printed become smaller or when there are multiple single pixel line segments that are closely spaced. A further advantage is that gray level data is left untouched and just binary data is enhanced.

The invention has been described with reference to certain preferred embodiments thereof. It will be understood, however, that modifications and variations can be made within the scope of the appended claims.

20

Industrial Utility

The invention can be utilized to process any low resolution binary image file for printing on any type of gray-scale printer including those employing lasers, LEDs, thermal, ink-jet or other printing elements or for use on a gray-scale display such as a CRT.

WHAT IS CLAIMED IS:

1. An image processing system comprising:
means (10) for storing a binary bitmap image file
including a plurality of pixel locations; means (16)
5 for determining a gradient magnitude corresponding to
each pixel location of the binary bitmap image file;
means (24) for determining a gradient direction
corresponding to each pixel location of the binary
bitmap image file; decision matrix means (28) for
10 comparing a window of the binary bitmap image file and
the gradient magnitudes and directions corresponding
thereto to predetermined sets of criteria and means,
responsive to said decision matrix means, for
generating enhanced gray-scale image data.
- 15 2. A system as claimed in Claim 1, wherein
said decision matrix means generates a look-up table
address in response to said comparing and said means
for generating enhanced gray-scale image data is a
look-up table (30).
- 20 3. A system as claimed in Claims 1 or 2,
wherein the decision matrix means (28) includes means
for rotating a window to a predetermined reference
direction in response to the gradient direction
information corresponding thereto.
- 25 4. A system as claimed in Claims 1, 2 or 3,
wherein the decision matrix means determines whether a
central pixel of a binary bitmap window is a black or
white pixel, whether the central pixel is located in a
single pixel width line, and the location of the
30 central pixel with respect to a kink site.
5. A system as claimed in any of Claims 1
through 4, and including means for storing mixed image
data including binary image data and gray-scale image
data; means for sorting the mixed image data to
35 generate sorted binary image data; and means for
selecting the mixed image data as output of the image
processing system if the mixed image data includes

gray-scale image data and for selecting the gray-scale enhanced binary image data if the mixed image data is binary image data.

- 5 6. A method of providing edge enhancement of
binary image data comprising the steps of storing a
binary bitmap image file including a plurality of pixel
locations; determining a gradient magnitude
corresponding to each pixel location of the binary
10 bitmap image file; determining a gradient direction
corresponding to each pixel location of the binary
bitmap image file, comparing a window of the binary
bitmap image file and the gradient magnitudes and
directions corresponding thereto to predetermined sets
of criteria, and in response to the comparing,
15 generating enhanced gray-scale image data.

7. A method of Claim 6 and including
generating a look-up table address in response to said
comparing and generating enhanced gray-scale image data
from said look-up table.

- 20 8. A method as claimed in Claims 6 or 7 and
including the step of rotating a window to a
predetermined reference direction in response to
gradient direction information corresponding thereto.

9. A method as claimed in Claims 6, 7 or 8
25 and wherein a determination is made of whether a
central pixel of the bitmap window is a black or white
pixel, whether the central pixel is located in a single
pixel width line, and the location of the central pixel
with respect to a kink site.

- 30 10. A method as claimed in any of Claims 6
through 9 and including the steps of storing mixed
image data including binary image data and gray-scale
image data; sorting the mixed image data to generate
sorted binary image data; and selecting the mixed image
35 data as an output if the mixed image data includes
gray-scale image data; and selecting the gray-scale

enhanced binary image data as a system output if the mixed image data is binary image data.

11. An image processing system comprising:
means for storing mixed image data including binary
5 image data and gray-scale image data; means for sorting
the mixed image data to generate sorted binary image
data; means for performing edge enhancement of the
sorted binary image data to produce gray-scale enhanced
binary image data; means for selecting the mixed image
10 data as the output of the image processing system if
the mixed image data includes gray-scale image data and
for selecting the gray-scale enhanced binary image data
if the mixed image data is binary image data.

12. An image processing system as claimed in
15 Claim 11, wherein said means for performing edge
enhancement comprises means for storing a bitmap image
file including a plurality of pixel locations; means
for determining a gradient magnitude corresponding to
each pixel location of the bitmap image file; means for
20 determining a gradient direction corresponding to each
pixel location of the bitmap image file; decision
matrix means for comparing a window of the bitmap image
file and the gradient magnitudes and directions
corresponding thereto to predetermined sets of criteria
25 and generating a look-up table address in response to
the comparing and a look-up table for generating gray-
scale enhanced binary image data in response to the
look-up table address.

13. A system as claimed in Claims 11 or 12,
30 wherein the decision matrix means includes means for
rotating the window to a predetermined reference
direction in response to the gradient direction
information corresponding thereto.

14. A system as claimed in Claims 11, 12 or
35 13, wherein the decision matrix means determines a
central pixel of the window is a black or white pixel,
whether the central pixel is located in a single pixel

width line, and the location of the central pixel with respect to a kink site.

15. An image processing method comprising the steps of storing mixed image data including binary
5 image data and gray-scale image data, sorting the mixed image data to generate sorted binary image data; performing an edge enhancement operation on the sorted binary image data to produce gray-scale enhanced binary image data; selecting the mixed image data as a system
10 output if the mixed image data includes gray-scale image data; and selecting the gray-scale enhanced binary image data as a system output if the mixed image data is binary image data.

16. A system of any of Claims 1 through 5 and
15 11 through 14 in combination with a gray-scale printer.

17. A system of any of Claims 1 through 5 and
11 through 14 in combination with a gray-scale display.

18. A method as claimed in any of Claims 6
through 10 and 15 and including the step of printing
20 the enhanced data with a gray-scale printer.

19. A method as claimed in any of Claims 6
through 10 and 15 and including the step of displaying
the enhanced data on a gray-scale display.

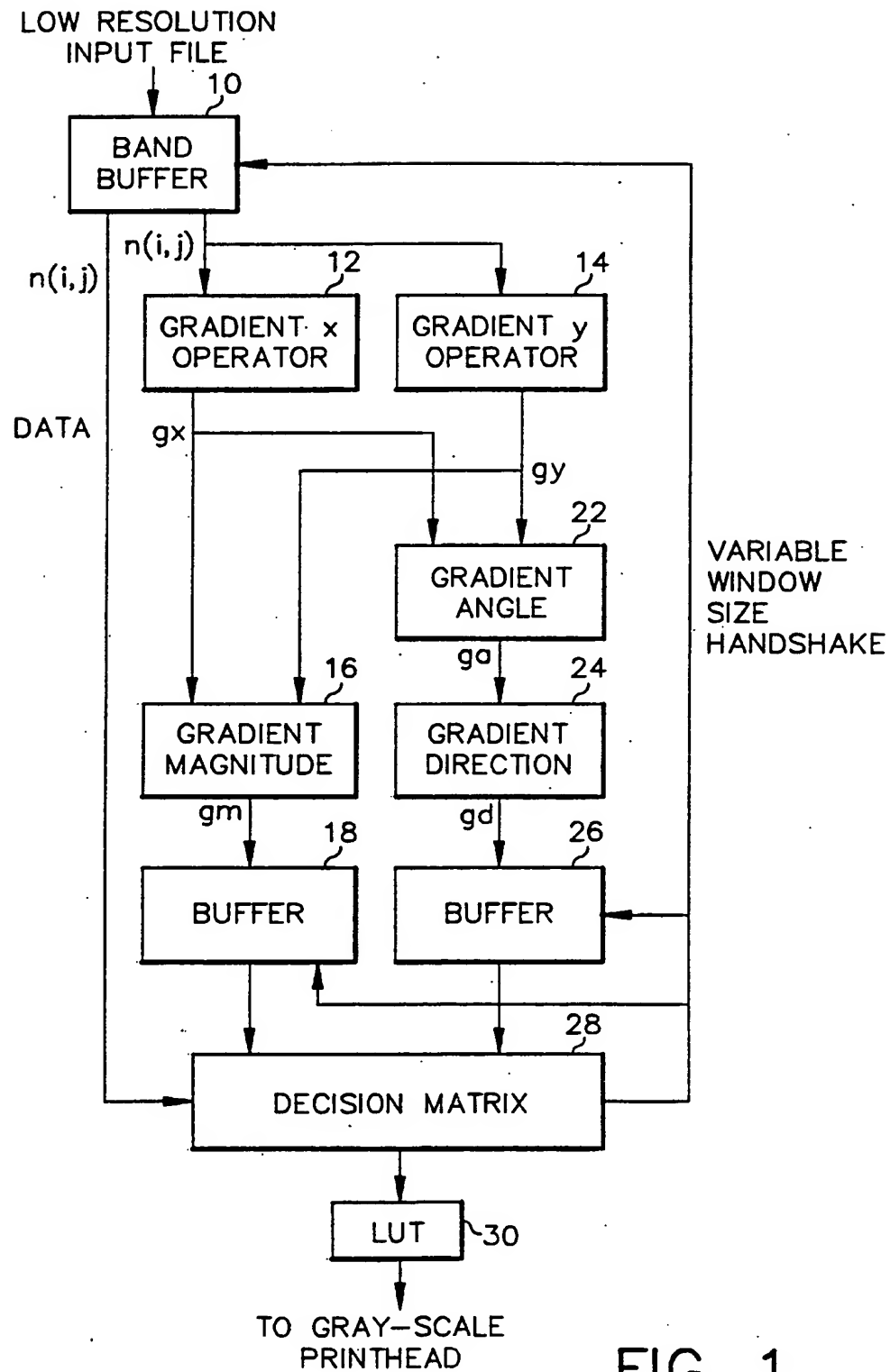


FIG. 1

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2A	2B
2C	2D

0	0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0	0
255	255	255	255	255	255	255	255	255
255	255	255	255	255	255	255	255	255
255	255	255	0	0	0	0	0	255
255	255	0	0	0	0	0	0	0
255	255	0	0	0	0	0	0	0
255	0	0	0	0	0	0	0	0
255	0	0	0	0	0	0	0	0
255	0	0	0	0	0	0	0	0
255	0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0	255
0	0	0	0	0	255	255	255	255
255	255	255	255	255	255	255	255	255
255	255	255	255	255	255	255	255	0
0	0	0	255	255	255	255	255	0

FIG. 2A

0	0	0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0	0	0
255	255	0	0	0	0	0	0	0	0
255	255	255	255	0	0	0	0	0	0
255	255	255	255	255	0	0	0	0	0
0	255	255	255	255	255	0	0	0	0
0	255	255	255	255	255	0	0	0	0
0	0	255	255	255	255	255	0	0	0
0	0	255	255	255	255	255	0	0	0
0	0	255	255	255	255	255	0	0	0
0	0	255	255	255	255	255	0	0	0
0	0	255	255	255	255	255	0	0	0
0	255	255	255	255	255	0	0	0	0
0	255	255	255	255	255	0	0	0	0
255	255	255	255	255	0	0	0	0	0
255	255	255	255	0	0	0	0	0	0
255	255	0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0	0	0

FIG. 2B

[illegible]

FIG. 2C

[illegible]

FIG. 2D

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3A	3B
3C	3D

0	0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0	0
806	1020	1020	1020	1020	1020	1020	1020	1020
1062	1020	1020	1020	1020	1020	1020	1020	1020
1020	0	361	806	1020	1020	1020	806	361
1020	361	1062	1140	1020	1020	1020	1140	1140
1020	806	1140	361	0	0	0	361	806
806	1140	806	0	0	0	0	0	0
361	1140	361	0	0	0	0	0	0
0	1020	0	0	0	0	0	0	0
0	1020	0	0	0	0	0	0	0
510	806	0	0	0	0	0	0	0
510	361	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0	361
0	0	0	0	0	0	0	361	1062
0	0	0	0	361	806	1020	1140	1062
806	1020	1020	1020	1140	1140	1020	806	0
1062	1020	1020	1020	806	361	0	361	1062
1062	1020	806	361	0	0	0	806	1140
806	1020	1062	806	0	0	0	1020	1020

FIG. 3A

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0	0	0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0	0	0
1020	806	361	0	0	0	0	0	0	0
1020	1140	1140	806	361	0	0	0	0	0
0	361	806	1140	1062	361	0	0	0	0
806	361	0	361	1062	1062	361	0	0	0
1020	806	0	0	361	1140	806	0	0	0
806	1140	361	0	0	806	1140	361	0	0
361	1140	806	0	0	361	1140	806	0	0
0	1020	1020	0	0	0	1020	1020	0	0
0	1020	1020	0	0	0	1020	1020	0	0
0	1020	1020	0	0	0	1020	1020	0	0
361	1140	806	0	0	361	1140	806	0	0
806	1140	361	0	0	806	1140	361	0	0
1140	806	0	0	361	1140	806	0	0	0
1062	361	0	361	1062	1062	361	0	0	0
361	361	806	1140	1062	361	0	0	0	0
806	1140	1140	806	361	0	0	0	0	0
1140	806	361	0	0	0	0	0	0	0
361	0	0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0	0	0

FIG. 3B

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4A	4B
4C	4D

0	0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0	0
252	270	270	270	270	270	270	270	270
225	270	270	270	270	270	270	270	270
180	0	45	72	90	90	90	106	135
180	45	45	63	90	90	90	117	117
180	18	27	45	0	0	0	135	106
162	27	18	0	0	0	0	0	0
135	27	45	0	0	0	0	0	0
0	0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0	0
90	18	0	0	0	0	0	0	0
90	45	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0	225
0	0	0	0	0	0	0	225	225
0	0	0	0	225	252	270	243	225
252	270	270	270	243	243	270	252	0
225	270	270	270	252	225	0	45	45
135	90	106	135	0	0	0	18	27
106	90	135	162	0	0	0	0	0

FIG. 4A

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0	0	0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0	0	0
270	265	315	0	0	0	0	0	0	0
270	297	297	268	315	0	0	0	0	0
0	316	266	297	315	315	0	0	0	0
106	135	0	315	315	315	315	0	0	0
136	162	0	0	315	333	342	0	0	0
162	153	135	0	0	342	333	315	0	0
135	153	162	0	0	315	333	342	0	0
0	180	180	0	0	0	0	0	0	0
0	180	180	0	0	0	0	0	0	0
0	180	180	0	0	0	0	0	0	0
225	207	196	0	0	45	27	16	0	0
196	207	225	0	0	16	27	45	0	0
207	196	0	0	45	27	16	0	0	0
225	225	0	45	45	45	45	0	0	0
225	45	72	63	45	45	0	0	0	0
72	63	63	72	45	0	0	0	0	0
63	72	45	0	0	0	0	0	0	0
45	0	0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0	0	0

FIG. 4B

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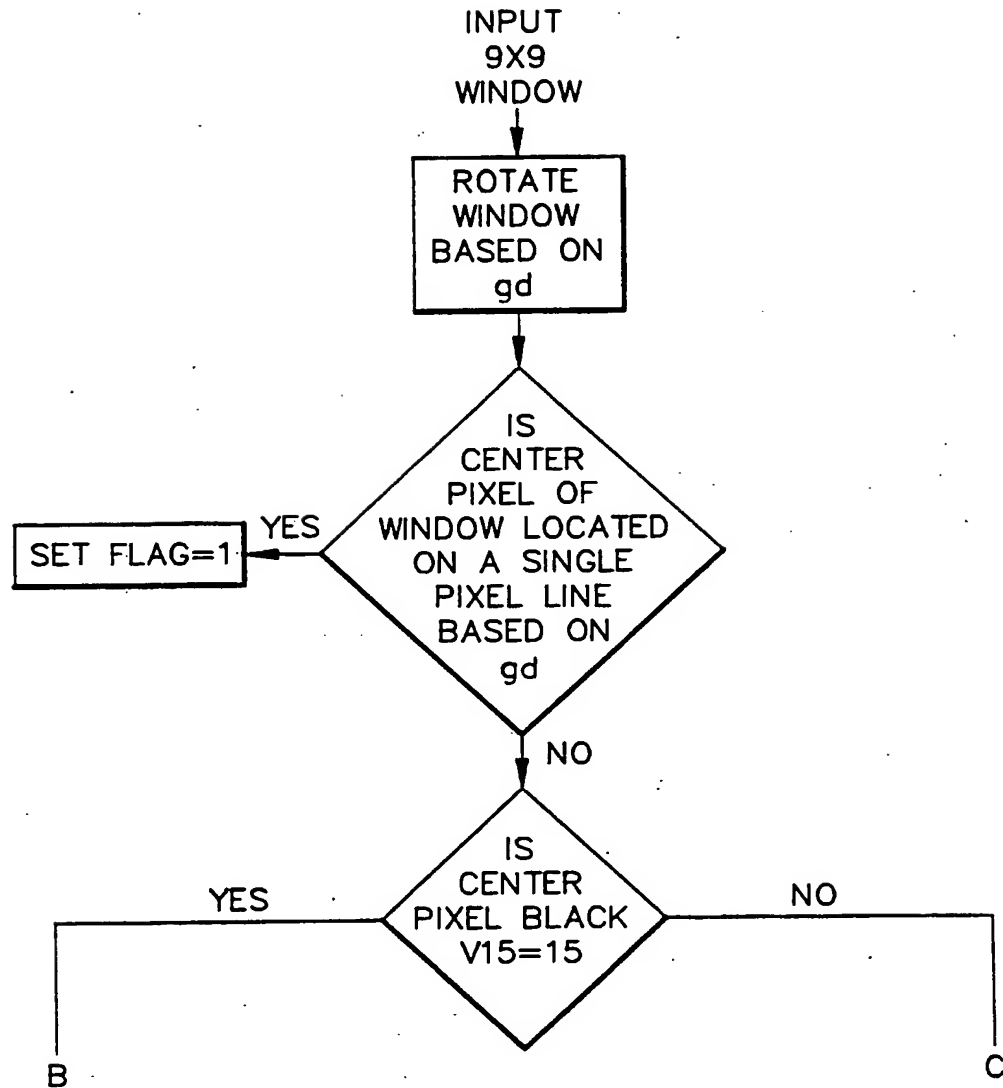


FIG. 5A

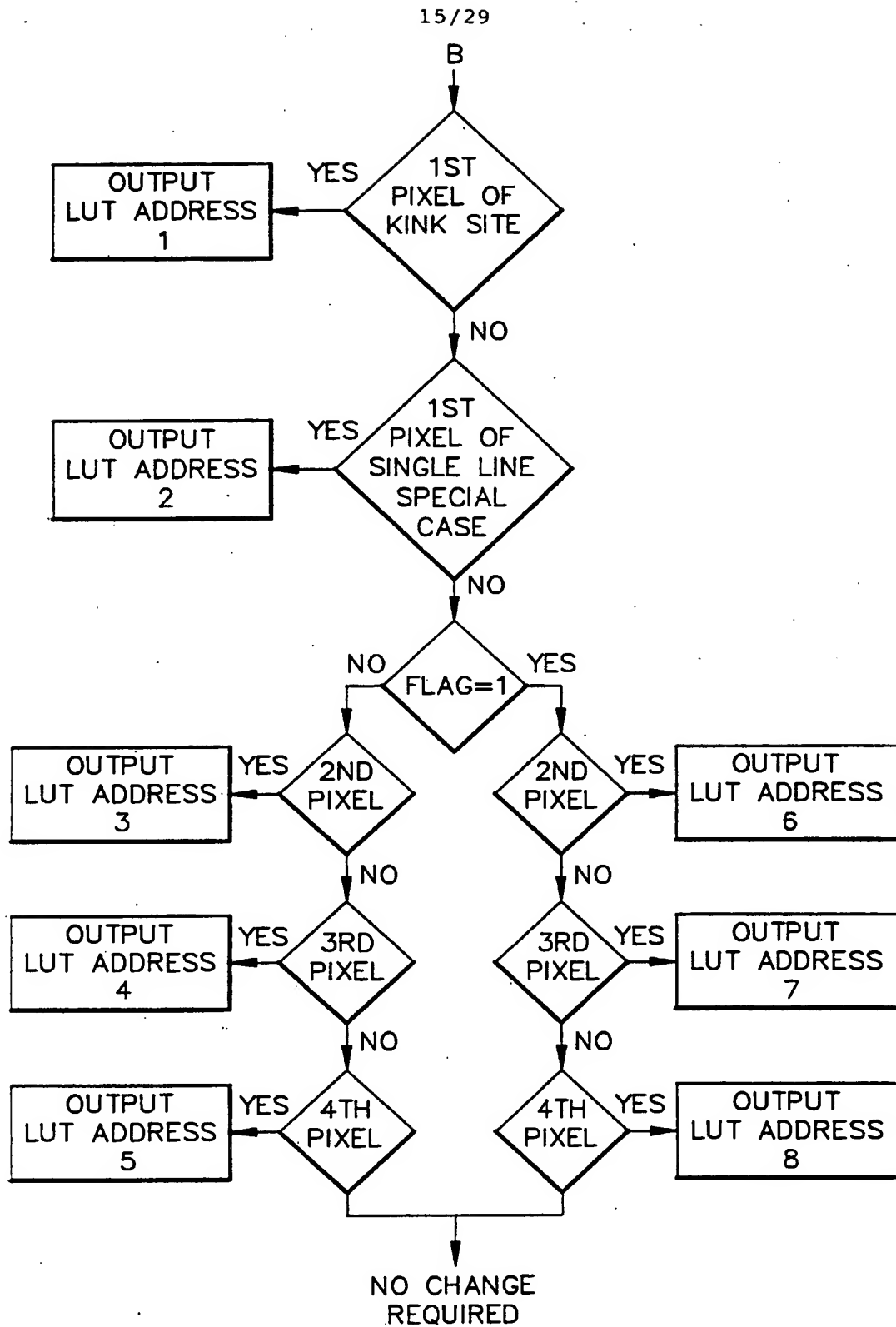


FIG. 5B

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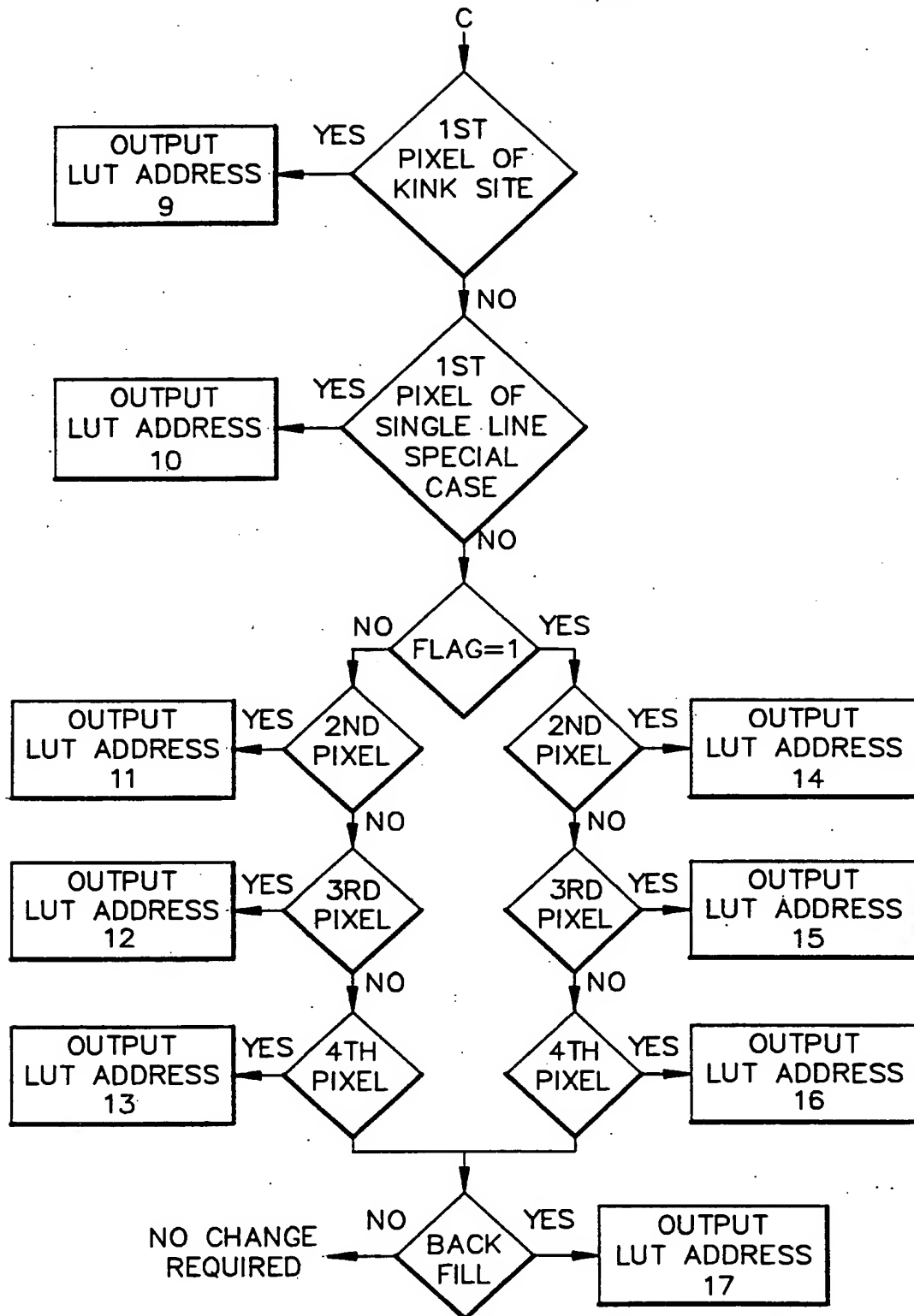


FIG. 5C

0	0	0	15	15	15	15	15
0	0	0	15	15	15	15	15
0	0	15	15	15	15	15	0
0	0	15	15	15	15	15	0
0	0	15	15	15	15	15	0
0	0	15	15	15	15	15	0
0	15	15	15	15	15	0	0
0	15	15	15	15	15	0	0

FIG. 6

0	0	0	0	0
0	15	15	15	15
15	15	15	15	15

FIG. 9

0	0	1	1	0	0	0	5
0	2	2	1	0	0	6	6
0	1	2	2	0	0	5	6
0	1	1	0	0	0	5	5
0	1	1	0	0	0	5	5
2	2	1	0	0	6	6	5
1	2	2	0	0	5	6	6
1	1	0	0	0	5	5	0

FIG. 7

2	3	3	3	2
2	2	3	3	3
3	2	0	0	0

FIG. 10

0	0	60	60	0	0	0	60
0	21	67	47	0	0	21	67
0	47	67	21	0	0	47	67
0	60	60	0	0	0	60	60
0	60	60	0	0	0	60	60
21	67	47	0	0	21	67	47
47	67	21	0	0	47	67	21
60	60	0	0	0	60	60	0

FIG. 8

21	47	60	60	67
67	67	60	60	47
47	21	0	0	0

FIG. 11

15	15	0
15	15	0
15	15	0
15	15	0
15	0	0

FIG. 12

67	47	0
60	60	0
60	60	0
47	67	21
27	67	47

FIG. 17

0	5	6
0	5	5
0	5	5
6	6	5
5	6	6

FIG. 13

0	15	15
0	15	15
0	15	15
0	15	15
0	0	15

FIG. 18

0	47	67
0	60	60
0	60	60
21	67	47
47	67	21

FIG. 14

2	3	0
3	3	0
3	3	0
3	2	2
2	2	3

FIG. 19

0	15	15
0	15	15
0	15	15
0	15	15
0	0	15

FIG. 15

67	47	0
60	60	0
60	60	0
47	67	21
21	67	47

FIG. 20

6	5	0
5	5	0
5	5	0
5	6	6
6	6	5

FIG. 16

0	0	15
0	15	15
0	15	15
0	15	15
0	15	15

FIG. 21

		V41	V21	V11	V31	V51		
			V22	V12	V32			
			V23	V13	V33			
		V44	V24	V14	V34	V54		
		V45	V25	V15	V35	V55		
		V46	V26	V16	V36	V56		
			V27	V17	V37			
			V28	V18	V38			
		V49	V29	V19	V39	V59		

FIG. 22

				d14				
			d25	d15	d35			
				d16				

FIG. 23

				a14				
				a15				
				a16				

FIG. 24

						V23		
				V44	V24	V13	V33	
			V45	V25	V14	V34		
		V46	V26	V15	V35	V54		
		V27	V16	V36	V55			
		V17	V37	V56				

FIG. 25

				d25	d14			
				d15	d35			
			d16					

FIG. 26

					a14			
				a15				
			a16					

FIG. 27

V49			V46	V45	V44			V41
V29	V28	V27	V26	V25	V24	V23	V22	V21
V19	V18	V17	V16	V15	V14	V13	V12	V11
V39	V38	V37	V36	V35	V34	V33	V32	V31
V59			V56	V55	V54			V51

FIG. 28

				d25				
			d16	d15	d14			
				d35				

FIG. 29

			a16	a15	a14			

FIG. 30

		V23						
	V33	V13	V24	V44				
		V34	V14	V25	V45			
		V54	V35	V15	V26	V46		
			V55	V36	V16	V27		
				V56	V37	V17		

FIG. 31

			d14	d25				
			d35	d15				
					d16			

FIG. 32

			a14					
				a15				
					a16			

FIG. 33

		V51	V31	V11	V21	V41		
			V32	V12	V22			
			V33	V13	V23			
		V54	V34	V14	V24	V44		
		V55	V35	V15	V25	V45		
		V56	V36	V16	V26	V46		
			V37	V17	V27			
			V38	V18	V28			
		V59	V39	V19	V29	V49		

FIG. 34

				d14				
			d35	d15	d25			
				d16				

FIG. 35

				a14				
				a15				
				a16				

FIG. 36

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						V33		
				V54	V34	V13	V23	
			V55	V35	V14	V24		
		V56	V36	V15	V25	V44		
		V37	V16	V26	V45			
		V17	V27	V46				

FIG. 37

				d35	d14			
				d15	d25			
			d16					

FIG. 38

					a14			
				a15				
			a16					

FIG. 39

V59			V56	V55	V54			V51
V39	V38	V37	V36	V35	V34	V33	V32	V31
V19	V18	V17	V16	V15	V14	V13	V12	V11
V29	V28	V27	V26	V25	V24	V23	V22	V21
V49			V46	V45	V44			V41

FIG. 40

				d35				
			d16	d15	d14			
				d25				

FIG. 41

			a16	a15	a14			

FIG. 42

		V33						
	V23	V13	V34	V54				
		V24	V14	V35	V55			
		V44	V25	V15	V36	V56		
			V45	V26	V16	V37		
				V46	V27	V17		

FIG. 43

			d14	d35				
			d25	d15				
					d16			

FIG. 44

			a14					
				a15				
					a16			

FIG. 45

0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0
15	15	15	0	0	0	0	0
0	0	0	15	15	15	15	15
0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0

FIG. 46

0	0	1	0	5	0	0	0
0	0	1	0	5	0	0	0
0	0	1	0	5	0	0	0
0	2	1	0	5	0	0	0
0	1	2	5	6	0	0	0
0	1	0	5	0	0	0	0
0	1	0	5	0	0	0	0
0	1	0	5	0	0	0	0

FIG. 49

0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0
3	3	3	4	0	0	0	0
0	0	4	3	3	3	3	3
7	7	7	8	0	0	0	0
0	0	8	7	7	7	7	7
0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0

FIG. 47

15	15	7
15	15	5
15	11	0
15	9	0
15	7	0

FIG. 50

0	0	0	15	0	0	0	0
0	0	0	15	0	0	0	0
0	0	0	15	0	0	0	0
0	0	0	15	0	0	0	0
0	0	15	0	0	0	0	0
0	0	15	0	0	0	0	0
0	0	15	0	0	0	0	0
0	0	15	0	0	0	0	0

FIG. 48

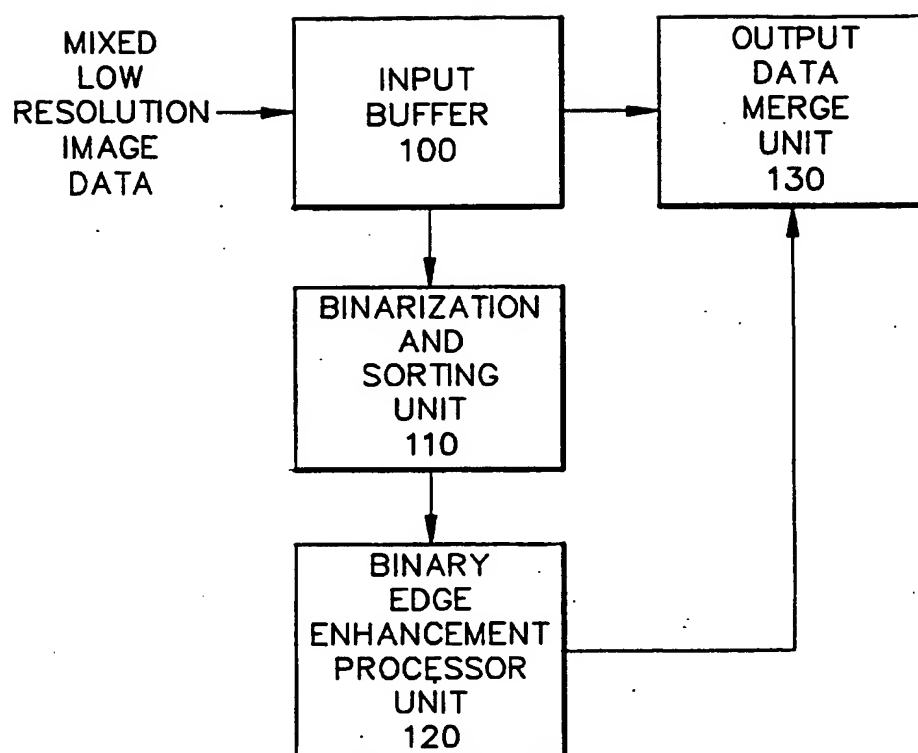


FIG. 51

13	14	13
14	15	14
13	14	13

FIG. 52

0	0	0
0	15	0
0	0	0

FIG. 53

0	0	15
0	15	15
0	15	15

FIG. 54

0	0	0	15	0	0	0	0
0	0	0	15	0	0	0	0
0	0	0	15	0	0	0	0
0	0	15	15	0	0	0	0
0	0	15	0	0	0	0	0
0	0	15	0	0	0	0	0
0	0	15	0	0	0	0	0
0	0	15	0	0	0	0	0

FIG. 55

INTERNATIONAL SEARCH REPORT

International Application No
PCT/US 93/11519

A. CLASSIFICATION OF SUBJECT MATTER

IPC 5 H04N1/40

According to International Patent Classification (IPC) or to both national classification and IPC

B. FIELDS SEARCHED

Minimum documentation searched (classification system followed by classification symbols)

IPC 5 H04N G06F G06K

Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched

Electronic data base consulted during the international search (name of data base and, where practical, search terms used)

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category *	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
X	EP,A,0 234 590 (DAINIPPON SCREEN) 2 September 1987.	1,4-6, 9-12, 14-19 3,8,13
Y	see abstract; figures 1-21 see page 15 - page 28 ---	
X	US,A,5 029 108 (LUNG) 2 July 1991	1,2,4,6, 7,9, 16-19 3,8
Y	see abstract; figures 1-15	5,10-15
A	see column 3, line 60 - column 4, line 16 see column 7, line 45 - column 8, line 28 ---	
Y	EP,A,0 199 502 (IBM) 29 October 1986	3,8,13
A	see column 11, line 25 - column 13, line 14; claims 8-10 ---	1,2,4,6, 7,9,11, 12,14, 15,17,19

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☒ Further documents are listed in the continuation of box C.

☒ Patent family members are listed in annex.

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Date of the actual completion of the international search

14 March 1994

Date of mailing of the international search report

30. 03. 94

Name and mailing address of the ISA

European Patent Office, P.B. 5818 Patentlaan 2
NL - 2280 HV Rijswijk
Tel. (+ 31-70) 340-2040, Tx. 31 651 epo nl,
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INTERNATIONAL SEARCH REPORT

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C.(Continuation) DOCUMENTS CONSIDERED TO BE RELEVANT

Category *	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
A	<p>IBM TECHNICAL DISCLOSURE BULLETIN vol. 28, no. 12 , May 1986 pages 5634 - 5637 'FAST ONE PIXEL EDGE DETECTOR' see the whole document -----</p>	<p>1,6,11, 12,15</p>

INTERNATIONAL SEARCH REPORT

Information on patent family members

International Application No

PCT/US 93/11519

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